OIPE JC108 NOV 1 6 2000 PATENT & TRADEMARK OFFICE

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference PAP110-PCT	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/SG 99/00039	International filing date (*day/month/year*) 11 May 1999 (11.05.99)	Priority Date (*day/month/year*) 13 May 1998 (13 May 98)
International Patent Classification (IPC) or national classification and IPC IPC^6: H 01 L 21/205		
Applicant NATIONAL UNIVERSITY OF SINGAPORE et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examination Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of ______ sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand 19 October 1999 (19.10.99)	Date of completion of this report 12 April 2000 (12.04.00)
Name and mailing address of the IPEA/AT Austrian Patent Office Kohlmarkt 8-10 A-1014 Vienna Facsimile No. 1/53424/200	Authorized officer Mayer Telephone No. 1/53424/452

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/SG 99/00039

I. Basis of the report

1. With regard to the **elements** of the international application:*

☒ the international application as originally filed

☐ the description:
pages ______, as originally filed
pages ______, filed with the demand
pages ______, filed with the letter of ______.

☐ the claims:
pages ______, as originally filed
pages ______, as amended (together with any statement) under Article 19
pages ______, filed with the demand
pages ______, filed with the letter of ______.

☐ the drawings:
pages ______, as originally filed
pages ______, filed with the demand
pages ______, filed with the letter of ______.

☐ the sequence listing part of the description:
pages ______, as originally filed
pages ______, filed with the demand
pages ______, filed with the letter of ______.

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language ______ which is:

☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

☐ the language of publication of the international application (under Rule 48.3(b)).

☐ the language of the translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/ or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. ☐ The amendments have resulted in the cancellation of:

☐ the description, pages ______.

☐ the claims, Nos. ______.

☐ the drawings, sheets/fig ______.

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as „originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.*

V. **Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1-12	YES
	Claims	-	NO
Inventive step (IS)	Claims	1-12	YES
	Claims	-	NO
Industrial applicability (IA)	Claims	1-12	YES
	Claims	-	NO

2. Citations and explanations (Rule 70.7)

The following documents are recorded in the Search Report:

D1: US 5863811 A
D2: JP 07-235692 A
D3: Patent Abstracts of Japan, unex. applic. E Section, Vol 17, Nr 466, Kokai No. A5-110138.

The ducument D1, which is considered to be the most relevant document, discloses a method forming a GaN buffer layer on the surface of a sapphire substrate by performing a VPE process. A GaN layer is then formed on the GaN buffer layer.

According to the essential features of present independent claims 1 and 12, document D1 does not describe a periodic or nonperiodic multi-layered buffer in which the layers alternate between at least two types of semiconductors A and B each different in lattice constant, energy band gap and layer thickness.

Documents D2 and D3 show further prior art buffer layers.

Dependent claims 2 to 11 are considered novel and inventive as well, showing preferred realizations of independent claim 1, respectively.

Industrial applicability is given.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
PAP110-PCT		
International application No. PCT/SG 99/00039	International filing date (*day/month/year*) 11 May 1999 (11.05.99)	(Earliest) Priority Date (*day/month/year*) 13 May ~~1999~~ 1998 (13.05.~~99~~ 98)
Applicant NATIONAL UNIVERSITY OF SINGAPORE et al.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      ☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing:
      ☐ contained in the international application in written form.
      ☐ filed together with the international application in computer readable form.
      ☐ furnished subsequently to this Authority in written form.
      ☐ furnished subsequently to this Authority in computer readable form.
      ☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      ☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.
2. ☐ **Certain claims were found unsearchable** (See Box I).
3. ☐ **Unity of invention is lacking** (See Box II).
4. With regard to the **title**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established by this Authority to read as follows:
5. With regard to the **abstract**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No.: 4
   ☒ as suggested by the applicant.
   ☐ None of the figures.
   ☐ because the applicant failed to suggest a figure.
   ☐ because this figure better characterizes the invention.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG 99/00039

A. CLASSIFICATION OF SUBJECT MATTER

IPC[6]: H 01 L 21/205

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[6]: H 01 L; H 01 S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	US 5 863 811 A (KAWAI et al.), 26 January 1999 (26.01.99), totality.	
A	Patent Abstracts of Japan, Vol.96, No.1, 31 January 1996 (31.01.96) & JP 07-235 692 A (SONY), 05 September 1995 (05.09.95).	1-12
A	Patent Abstracts of Japan, unex.applic. E Section, Vol.17, Nr.466 (25.August 1993), The Patent Office Japanese Government, page 34E1421, Kokai No. A5-110138 (NICHIA CHEM.).	1-12

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

„A" document defining the general state of the art which is not considered to be of particular relevance

„E" earlier application or patent but published on or after the international filing date

„L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

„O" document referring to an oral disclosure, use, exhibition or other means

„P" document published prior to the international filing date but later than the priority date claimed

„T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

„X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

„Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

„&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 September 1999 (08.09.99)	16 September 1999 (16.09.99)
Name and mailing adress of the ISA/AT Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna Facsimile No. 1/53424/200	Authorized officer Mayer Telephone No. 1/53424/452

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SG 99/00039

Im Recherchenbericht angeführtes Patentdokument Patent document cited in search report Document de brevet cité dans le rapport de recherche	Datum der Veröffentlichung Publication date Date de publication	Mitglied(er) der Patentfamilie Patent family member(s) Membre(s) de la famille de brevets	Datum der Veröffentlichung Publication date Date de publication
US A 5863811	26-01-1999	JP A2 9018092	17-01-1997
JP A2 7235692	05-09-1995	keine - none - rien	

Original (for SUBMISSION) - printed on 07.05.1999 04:28:05 PM

0 0-1	**For receiving Office use only** International Application No.	
0-2	International Filing Date	
0-3	Name of receiving Office and "PCT International Application"	

0-4 0-4-1	**Form - PCT/RO/101 PCT Request** Prepared using	PCT-EASY Version 2.83 (updated 01.03.1999)
0-5	**Petition** The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty	
0-6	**Receiving Office (specified by the applicant)**	Registry of Patents (Singapore) (RO/SG)
0-7	**Applicant's or agent's file reference**	PAP110-PCT
I	**Title of invention**	CRYSTAL GROWTH METHOD FOR GROUP-III NITRIDE AND RELATED COMPOUND SEMICONDUCTORS
II	**Applicant**	
II-1	This person is:	applicant only
II-2	Applicant for	all designated States except US
II-4	Name	NATIONAL UNIVERSITY OF SINGAPORE
II-5	Address:	10 Kent Ridge Crescent Singapore 119260 119260 Singapore Singapore
II-6	State of nationality	SG
II-7	State of residence	SG
II-8	Telephone No.	65-8742987
II-9	Facsimile No.	65-7776990
III-1	**Applicant and/or inventor**	
III-1-1	This person is:	applicant and inventor
III-1-2	Applicant for	US only
III-1-4	Name (LAST, First)	ZHANG, Xiong
III-1-5	Address:	c/o INTRO, National University of Singapore 10 Kent Ridge Crescent 119260 Singapore Singapore
III-1-6	State of nationality	CN
III-1-7	State of residence	SG

III-2	**Applicant and/or inventor**	
III-2-1	This person is:	applicant and inventor
III-2-2	Applicant for	US only
III-2-4	Name (LAST, First)	CHUA, Soo Jin
III-2-5	Address:	c/o INTRO, National University of Singapore 10 Kent Ridge Crescent 119260 Singapore Singapore
III-2-6	State of nationality	MY
III-2-7	State of residence	SG
IV-1	**Agent or common representative; or address for correspondence** The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as:	agent
IV-1-1	Name	APPLIED RESEARCH CORPORATION
IV-1-2	Address:	Kent Ridge P.O.BOX 1016 911101 Singapore Singapore
IV-1-3	Telephone No.	65-7755822
IV-1-4	Facsimile No.	65-7730924
IV-1-5	e-mail	arc@pacific.net.sg
V	**Designation of States**	
V-1	Regional Patent (other kinds of protection or treatment, if any, are specified between parentheses after the designation(s) concerned)	EP: AT BE CH&LI CY DE DK ES FI FR GB GR IE IT LU MC NL PT SE and any other State which is a Contracting State of the European Patent Convention and of the PCT
V-2	National Patent (other kinds of protection or treatment, if any, are specified between parentheses after the designation(s) concerned)	JP US
V-5	**Precautionary Designation Statement** In addition to the designations made under items V-1, V-2 and V-3, the applicant also makes under Rule 4.9(b) all designations which would be permitted under the PCT except any designation(s) of the State(s) indicated under item V-6 below. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit.	
V-6	**Exclusion(s) from precautionary designations**	NONE

PCT REQUEST

Original (for SUBMISSION) - printed on 07.05.1999 04:28:05 PM

VI-1	Priority claim of earlier national application		
VI-1-1	Filing date	13 May 1998 (13.05.1998)	
VI-1-2	Number	9801054-9	
VI-1-3	Country	SG	
VI-2	Priority document request The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) identified above as item(s):	VI-1	
VII-1	International Searching Authority Chosen	Austrian Patent Office (ISA/AT)	
VIII	Check list	number of sheets	electronic file(s) attached
VIII-1	Request	4	-
VIII-2	Description	11	-
VIII-3	Claims	3	-
VIII-4	Abstract	1	abstract.txt
VIII-5	Drawings	7	-
VIII-7	TOTAL	26	
	Accompanying items	paper document(s) attached	electronic file(s) attached
VIII-8	Fee calculation sheet	✓	-
VIII-16	PCT-EASY diskette	-	diskette
VIII-18	Figure of the drawings which should accompany the abstract	FIG. 4	
VIII-19	Language of filing of the international application	English	
IX-1	Signature of applicant or agent	OngChorEong	
IX-1-1	Name	APPLIED RESEARCH CORPORATION	
IX-1-2	Name of signatory	ONG Chor Eong	
IX-1-3	Capacity	Managing Director	

FOR RECEIVING OFFICE USE ONLY

10-1	Date of actual receipt of the purported international application	
10-2	Drawings:	
10-2-1	Received	
10-2-2	Not received	
10-3	Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application	
10-4	Date of timely receipt of the required corrections under PCT Article 11(2)	
10-5	International Searching Authority	ISA/AT
10-6	Transmittal of search copy delayed until search fee is paid	

FOR INTERNATIONAL BUREAU USE ONLY

11-1	Date of receipt of the record copy by the International Bureau	

3

REC'D 24 AUG 2000
WIPO PCT

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference PAP110-PCT	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/SG 99/00039	International filing date (*day/month/year*) 11 May 1999 (11.05.99)	Priority Date (*day/month/year*) 13 May 1998 (13 May 98)
International Patent Classification (IPC) or national classification and IPC IPC^6: H 01 L 21/205		
Applicant NATIONAL UNIVERSITY OF SINGAPORE et al.		

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2. This REPORT consists of a total of 3 sheets, including this cover sheet.

☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of ______ sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☐ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
19 October 1999 (19.10.99)	12 April 2000 (12.04.00)
Name and mailing address of the IPEA/AT Austrian Patent Office Kohlmarkt 8-10 A-1014 Vienna Facsimile No. 1/53424/200	Authorized officer Mayer Telephone No. 1/53424/452

Form PCT/IPEA/409 (cover sheet) (July 1998)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/SG 99/00039

I. Basis of the report

1. With regard to the **elements** of the international application:*

☒ the international application as originally filed

☐ the description:
pages __________, as originally filed
pages __________, filed with the demand
pages __________, filed with the letter of __________.

☐ the claims:
pages __________, as originally filed
pages __________, as amended (together with any statement) under Article 19
pages __________, filed with the demand
pages __________, filed with the letter of __________.

☐ the drawings:
pages __________, as originally filed
pages __________, filed with the demand
pages __________, filed with the letter of __________.

☐ the sequence listing part of the description:
pages __________, as originally filed
pages __________, filed with the demand
pages __________, filed with the letter of __________.

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language __________ which is:

☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

☐ the language of publication of the international application (under Rule 48.3(b)).

☐ the language of the translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. ☐ The amendments have resulted in the cancellation of:

☐ the description, pages __________.

☐ the claims, Nos. __________.

☐ the drawings, sheets/fig __________.

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as „originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.*

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	1-12	YES
	Claims	-	NO
Inventive step (IS)	Claims	1-12	YES
	Claims	-	NO
Industrial applicability (IA)	Claims	1-12	YES
	Claims	-	NO

2. Citations and explanations (Rule 70.7)

The following documents are recorded in the Search Report:

D1: US 5863811 A
D2: JP 07-235692 A
D3: Patent Abstracts of Japan, unex. applic. E Section, Vol 17, Nr 466, Kokai No. A5-110138.

The ducument D1, which is considered to be the most relevant document, discloses a method forming a GaN buffer layer on the surface of a sapphire substrate by performing a VPE process. A GaN layer is then formed on the GaN buffer layer.

According to the essential features of present independent claims 1 and 12, document D1 does not describe a periodic or nonperiodic multi-layered buffer in which the layers alternate between at least two types of semiconductors A and B each different in lattice constant, energy band gap and layer thickness.

Documents D2 and D3 show further prior art buffer layers.

Dependent claims 2 to 11 are considered novel and inventive as well, showing preferred realizations of independent claim 1, respectively.

Industrial applicability is given.

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification [6] :
H01L 21/205

A1

(11) International Publication Number: WO 99/59195

(43) International Publication Date: 18 November 1999 (18.11.99)

(21) International Application Number: PCT/SG99/00039

(22) International Filing Date: 11 May 1999 (11.05.99)

(30) Priority Data:
9801054–9 13 May 1998 (13.05.98) SG

(71) Applicant *(for all designated States except US)*: NATIONAL UNIVERSITY OF SINGAPORE [SG/SG]; 10 Kent Ridge Crescent, Singapore 119260 (SG).

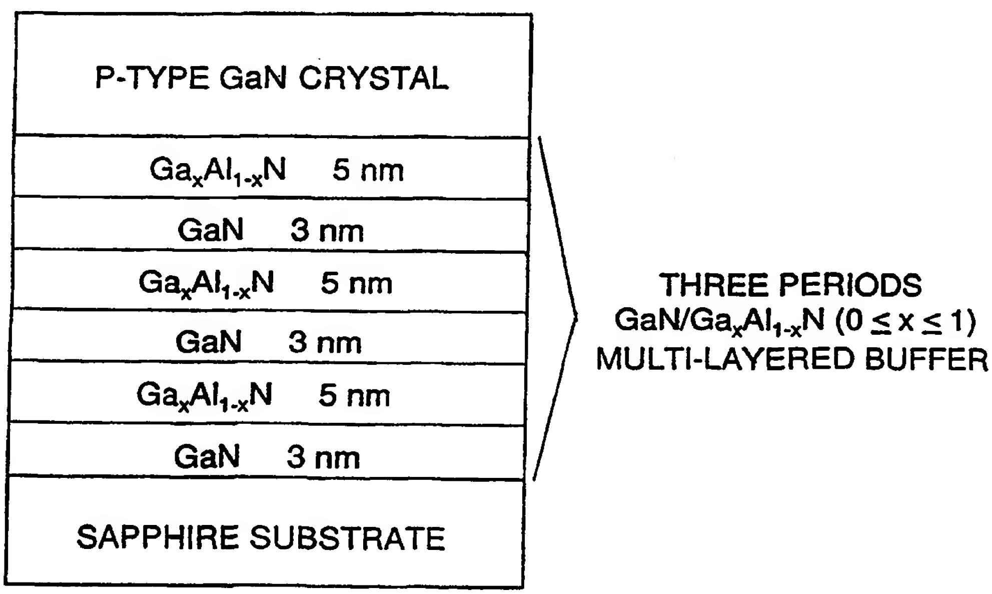
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: ZHANG, Xiong [CN/SG]; INTRO, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260 (SG). CHUA, Soo, Jin [MY/SG]; INTRO, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260 (SG).

(74) Agent: APPLIED RESEARCH CORPORATION; Kent Ridge, P.O. Box 1016, Singapore 911101 (SG).

(81) Designated States: JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: CRYSTAL GROWTH METHOD FOR GROUP–III NITRIDE AND RELATED COMPOUND SEMICONDUCTORS



(57) Abstract

Crystals of group–III nitride and related compound semiconductors are grown on the surface of a periodic or nonperiodic multi–layered buffer in which the layers alternate between two types of compound semiconductors A and B, different from each other in lattice constant and energy band gap. The crystallinity of the group–III nitride and related compound semiconductors grown on the surface of such a multi–layered buffer can be significantly improved.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
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BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
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BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's	**NZ**	New Zealand		
CM	Cameroon		Republic of Korea	**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

CRYSTAL GROWTH METHOD FOR GROUP-III NITRIDE AND RELATED COMPOUND SEMICONDUCTORS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method for growing group-III nitrides and related compound semiconductors on a substrate consisting of, for example, sapphire and, more particularly, to a method for growing epitaxial layers of group-III nitride and related compound semiconductors by means of metalorganic chemical vapor deposition (to be referred to as MOCVD hereinafter).

2. Description of the Related Art

To realize high-efficiency, high-brightness blue and ultraviolet light-emiting diodes and lasers, group-III nitride and related compound semiconductors have been researched and developed in recent years. As a method for growing group-III nitride and related compound semiconductors, MOCVD is currently widely used.

In a typical MOCVD process, group-III nitride and related compound semiconductors are generally grown hetero-epitaxially on sapphire substrates. However, due to the large differences in lattice constant and thermal expansion coefficient between the group-III nitride and sapphire, it is really difficult to obtain high quality epitaxial layers of group-III nitride and related compound semiconductors. In order to solve this problem, several methods have been proposed in the past decade. The first one was demonstrated by Amano, et al. (U. S. Patent 4,855,249, and Appl. Phys. Lett. Vol. 48, 1986, pp. 353-355) who grew the group-III nitride and related compound semiconductors on a low-temperature grown AlN single buffer layer instead of growing them directly on the sapphire substrates. The second and now widely adopted method was proposed by Nakamura et al. (U. S. Patent 5,290,393 amd Jpn. J. Appl. Phys. Vol. 32, 1993, pp. L16-L19). According to this method, a $Ga_xAl_{1-x}N$ ($0 < x \leq 1$) single buffer layer was grown on the sapphire substrate at low temperature prior to the growth of the group-III nitride and related compound semiconductor films. More recently, a new method has been developed by Uchida et al. (Proceedings of the Second International Conference on Nitride

Semiconductors, Tokushima, Japan, 1997, pp. 214-215) and Turnbull et al. (J. Appl. Phys. Vol. 80, 1996, pp. 4609-4614). In this method, the so-called double buffer layers which consist of two GaN layers or one GaN and one AlN layer, deposited successively at two different or identical temperatures, were firstly grown on the sapphire substrate, and the group-III nitride and related compound semiconductor films were then grown on the specially designed double buffer layers.

By making use of these recently developed technologies (especially the second one), blue-light emitting diodes based on the group-III nitride and related compound semiconductors have become commercially available. However, according to these conventionally proposed methods, not only the growth conditions, such as the growth temperature for the single or double buffer layers and the thickness of the buffer layer are strictly restricted (most satisfactory result reported up to date has been achieved at a growth temperature of 450 °C and a total layer thickness of 25 nm when employing these buffers) , but also the material combination is quite limited (so far only GaN and $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) were used as the buffer layers), which may prevent them from meeting the objectives of fabricating good quality optoelectronic devices. Therefore, the crystal growth method needs to be further improved in order to enhance the crystallinity of the group-III nitride and related compound semiconductors.

SUMMARY OF THE INVENTION

The present invention has been made in consideration of the above situation and has as one of its objectives, to provide a crystal growth method for the group-III nitride and related compound semiconductors, yielding as high a crystal quality as possible while maintaining freedom in choosing material systems for practical applications.

It is another objective of the present invention to provide a method which can grow a p- or n-type semiconductor layer with an excellent characteristic so as to allow formation of an excellent p-n junction for use in a nitride-based light-emitting device and a laser diode.

According to the present invention, there is provided a crystal growth method for the group-III nitride and related compound semiconductors, comprising of the following steps:

Forming a MOCVD-grown periodic or nonperiodic multi-layered buffer on a substrate at a first temperature, in which the layers alternate between two types of compound semiconductors A and B different from each other in lattice constant, energy band gap, layer thickness, and composition; and

Forming a MOCVD-grown layer of a group-III nitride or related compound semiconductor on the formed multi-layered buffer, at a second temperature which is higher than the first.

According to the present invention, a group-III nitride or related compound semiconductor layer can be doped n- or p-type as it is MOCVD-grown on the obtained buffer formed on a substrate.

Additional objectives and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objectives and advantages of the invention may be realized and obtained by means of the techniques and combinations thereof particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated and constitute a part of the specification, illustrate presently preferred embodiments of the invention, and together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a schematic sectional view showing a $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) crystal grown on a conventional AlN single buffer layer on a sapphire substrate;

FIG. 2 is a schematic sectional view showing a $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) crystal grown on a conventional $Ga_yAl_{1-y}N$ ($0 < y \leq 1$) single buffer layer on a sapphire substrate;

FIG. 3 is a schematic sectional view showing a $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) crystal grown on a conventional GaN/GaN double buffer layers on a sapphire substrate;

FIG. 4 is a schematic sectional view showing a p-type GaN crystal grown on a periodic and alternating GaN/$Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) multi-layered buffer on a sapphire substrate according to Example 1 of the present invention;

FIG. 5 is a graph showing the relationship between the normalized photoluminescence (PL) intensity of the p-GaN (Mg doped) films and the number of the periods of alternating GaN/$Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) in the multi-layered buffer according to Example 1 of the present invention. For the purpose of comparison, the results of the p-GaN films obtained according to the conventional growth methods, i.e., using a GaN or $Ga_yAl_{1-y}N$ ($0 \leq y \leq 1$) single buffer layer, and GaN/$Ga_yAl_{1-y}N$ ($0 \leq y \leq 1$) double buffer layers, are also shown in this figure;

FIG. 6 is a schematic sectional view showing a n-type GaN crystal grown on a periodic and alternating GaN/$Ga_xIn_{1-x}N$ ($0 \leq x \leq 1$) multi-layered buffer on a sapphire substrate according to Example 2 of the present invention;

FIG. 7 is a schematic sectional view showing a p-type $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) crystal grown on a nonperiodic multi-layered buffer consisting of alternating GaN/$Ga_yAl_{1-y}N$ ($0 \leq y \leq 1$) in which each GaN or $Ga_yAl_{1-y}N$ layer has different layer thickness on a sapphire substrate according to Example 3 of the present invention;

FIG. 8 is a schematic sectional view showing a n-type $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) crystal grown on a nonperiodic multi-layered buffer consisting of alternating GaN/$Ga_yIn_{1-y}N$ ($0 \leq y \leq 1$) in which each $Ga_yIn_{1-y}N$ layer has different y value, i.e. different Ga and In composition on a sapphire substrate according to Example 4 of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to the present invention, a periodic or nonperiodic multi-layered buffer in which the layers alternate between two types of compound semiconductors A and B different from each other in lattice constant and energy band gap, is grown on a sapphire substrate by means of MOCVD at a first (low) temperature before the growth of the group-III nitride or related compound semiconductors. Since the growth temperature for this multi-layer buffer layer is usually much lower than the temperature at which a nitride single crystal can be formed, the buffer layer is of an amorphous or polycrystalline state, as confirmed by our experiment and reported by other reseach groups over the world. In fact, this is just the reason why we name the buffer of the present invention as "multi-layered buffer" rather than "multi-quantum wells or superlattice buffer". Although the layered structure of the latter is somewhat similar to that of the former, following the definition,

multi-quantum wells and superlattice are strictly periodically formed monocrystalline whereas the multi-layered buffer of the present invention is amorphous or polyscrystalline and may not be formed periodically, i.e., each layer in the buffer can have a different layer thickness and/or composition.

As the temperature is raised to the second (high) temperature for the growth of the group-III nitride-based compound semiconductor crystals on the multi-layered buffer, the amorphous or polycrystalline buffer will partially change to monocrystalline due to the recrystallizing effect to serve as seed crystal. Compared with the conventional single or double buffer, the multi-layered buffer of the present invention demonstrates the ability to accommodate the strain arising from the lattice mismatch between the group-III nitride-based compound semiconductors and the sapphire substrate, and to form the seed crystal more effectively. According to the present invention, the crystalline quality of the group-III nitride-based compound semiconductors can be significantly enhanced by using the multi-layered buffer because the strain-accommodating and recrystallizing effects which are of crucial importance in improving the crystalline quality of the group-III nitride-based compound semiconductors, seemed to be more profound in the multi-layered buffer than in the single and double buffer layers. Moreover, since there is neither any limitation on selecting the constituent semiconductors of the multi-layered buffer, nor strict restriction on the layer thickness and the composition of each layer in the buffer, one can choose with great freedom the appropriate material combination to form the multi-layered buffer as convenient as possible for the subsequent growth of group-III nitride-based compound semiconductors on the formed multi-layered buffer. Note that although the multi-layered buffer of the present invention is amorphous (or polycrystal in some cases) and may not be formed periodically, i.e., each layer in the buffer can have different layer thickness and composition, there are of course optimal layer thickness and composition which depend on the constituent semiconductors and how they form the buffer (combination). A similar situation applies with respect to the growth conditions for the multi-layered buffer as well as the subsequently grown group-III nitrides and related compound semiconductors. However, in general, the preferred growth (said first or low) temperature for the buffer is within the range of (500-550 °C). On the other hand, the second or high growth temperature for the group-III nitride-based compound semiconductors is preferably 1,000 to 1,100 °C. Furthermore, in the case wherein the multi-layered buffer is formed periodically on a sapphire substrate, this buffer can be expressed by the formula

AB......AB. Here A and B represent one of two types of compound semiconductors different from each other in lattice constant and energy band gap.

In the present invention, the multi-layered buffer can be formed not only on a sapphire substrate but also on any substrate which are presently, already used or may be developed in the future, such as Si, SiC, GaP, InP, and GaAs substrates. It can even be formed on the surface of the epitaxial layers of the group-III nitrides and/or related compound semiconductors. This characteristic implies that the multi-layered buffer of the present invention can be applied to the regrowth of the group-III nitrides and/or related compound semiconductors.

Examples of the present invention will be described below with reference to the accompanying drawings. First, periodic and alternating $GaN/Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) multi-layered buffer on a sapphire substrate (Example 1) which can overcome the drawbacks of conventional growth methods employing single or double buffers will be described in detail. Subsequently, several specific multi-layered buffers which are periodic or nonperiodic in layer thickness and composition (Examples 2 to 4) will be described. These examples, however, merely exemplify the method of practicing the technical concepts of the present invention. Therefore, the method of the present invention is not particularly limited to the following examples in terms of, for example, the growth conditions and the combination of the materials used. Various modifications can be made for the growth method of the present invention in accordance with the scope of claims.

Example 1

FIG. 4 shows a p-type GaN crystal grown on a periodic and alternating $GaN/Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) multi-layered buffer on a sapphire substrate according to Example 1 of the present invention. Referring to FIG. 4, GaN and $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) thin films are periodically and alternately grown on a chemically cleaned sapphire substrate at a first (low) temperature of 525 °C. The film thickness of GaN and $Ga_xAl_{1-x}N$ are set to 3 nm and 5 nm, respectively. The number of the $GaN/Ga_xAl_{1-x}N$ repeated unit is changed from 3 to 12, corresponding to a total layer thickness of the multi-layered buffer varying from 24 nm to 96 nm. Subsequently, a 2 μm-thick Mg-doped p-type GaN epitaxial layer (monocrystalline) is grown on the surface of the formed multi-layered buffer at a second

(high) temperature of 1,050 °C. For comparison with the conventional methods using AlN (FIG. 1) and GaN (FIG. 2) single buffer, and GaN/GaN double buffers (FIG. 3), a single GaN buffer and a single $Ga_xAl_{1-x}N$ buffer with an identical layer thickness of 25 nm which is the optimal value reported so far in the case of single buffer layer, are stacked on sapphire substrates, respectively. In addition, the $GaN/Ga_yAl_{1-y}N$ $(0 \leq y \leq 1)$ double buffers in which each buffer has the same layer thickness of 10 nm and was deposited successively at two different temperatures of 600 and 500 °C were also grown on sapphire substrate in the same way as that reported by Uchida et al.

After the growth, a Hall effect measurement was performed at room temperature to determine the electronic properties, more specifically, the majority carrier concentration, the mobility, and the resistivity of the p-type GaN epitaxial layer. On the other hand, a photoluminescence (PL) measurement was carried out at room temperature in order to characterize the crystalline quality of the grown p-type GaN epitaxial layers and to compare the optical property, more specifically, the PL intensity of the p-type GaN samples grown by using the multi-layered buffer with those samples grown by means of the conventional buffers. According to the Hall measurement results, for example, the majority carrier concentration, the mobility, and the resistivity of the p-type GaN sample grown by using three periods $GaN/Ga_yAl_{1-y}N$ $(y=0.1)$ multi-layered buffer, are 2.2×10^{17} cm^{-3}, 14.5 $cm^2/Vsec.$, and 1.5 Ωcm, respectively. These values are slightly better than the corresponding results reported recently by Nakamura and Fasol ("The blue light laser diode", Springer, 1997) who used a single GaN buffer layer. On the other hand, the optical property, more specifically, the PL intensity of the p-type GaN samples grown by using the multi-layered buffer of the present invention was found to be much stronger than those samples grown by using conventional single or double buffers provided that the number of the periods of $GaN/Ga_xAl_{1-x}N$ $(0 \leq x \leq 1)$ in the multi-layered buffer is less than 6 or the total layer thickness of the multi-layered buffer is thinner than 48 nm.

FIG. 5 shows the relationship between the normalized PL intensity of the p-GaN (Mg doped) films and the number of the periods of alternating $GaN/Ga_xAl_{1-x}N$ $(0 \leq x \leq 1)$ in the multi-layered buffer according to Example 1 of the present invention. The results of the p-GaN films obtained according to the conventional growth methods, i.e., using a single GaN or $Ga_yAl_{1-y}N$ $(0 \leq y \leq 1)$, or $GaN/Ga_yAl_{1-y}N$ $(0 \leq y \leq 1)$ double buffer layers, are also shown in this figure. As is apparent from FIG. 5, the PL intensity of the p-type GaN

samples grown by using the multi-layered buffers are much stronger than those grown by using conventional methods provided that the number of the periods of $GaN/Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) multi-layered buffer is less than 6 or the total layer thickness of the multi-layered buffer is thinner than 48 nm. This fact indicates that by using the multi-layered buffer, the crystalline quality of the group-III nitrides and related compound semiconductors can be significantly improved. Furthermore, most intense PL signal was detected from the p-type GaN sample in which a multi-layered buffer with three periods of $GaN/Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) and a total layer thickness of 24 nm. This phenomenon implies that there should be optimal values for the number of periods of the $GaN/Ga_xAl_{1-x}N$ and the total layer thickness of the multi-layered buffer. These optimal values, of course, are strongly dependent on the layer thickness and the composition of each constituent layer, as well as the material combination selected for the multi-layered buffer.

Unfortunately at the present time there is no reliable theory in terms of which one can explain the physical mechanism of the multi-layered buffer and determine or predict the optimal layer thickness of the multi-layered buffer for a special material combination. In other words, the optimal value for a special material combination can now only be determined by experiment. However, the existence of the optimal layer thickness for the multi-layered buffer can be interpreted qualitatively as follows. Generally a buffer layer grown at a low temperature provides seed crystals which act as nucleation sites with low orientational fluctuation to promote the lateral growth of the group-III nitrides. A double buffer, especially a multi-layered buffer provide additional interfaces for the misfit dislocations to terminate. However, if the multi-layer buffer is too thin, it may neither effectively accommodate the elastic strain due to the large lattice mismatch between the group-III nitride crystals and the sapphire substrate nor provide sufficient amount of seed crystals for the subsequent growth of the group-III nitrides. On the other hand, if the multi-layered buffer is too thick, it tends to bring about excessive amount of the seed crystals with high orientational fluctuation. Therefore, there should be an optimal layer thickness for the multi-layered buffer. As shown in FIG. 5, the present inventors have experimentally found that most intense PL intensity can be obtained by using a multi-layered buffer with three periods of $GaN/Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) and a total layer thickness of 24 nm which is near the optimized layer thickness for single and double buffer layers reported so far.

Example 2

FIG. 6 is a schematic sectional view showing a n-type GaN crystal grown on a periodic and alternating $GaN/Ga_xIn_{1-x}N$ ($0 \leq x \leq 1$) multi-layered buffer on a sapphire substrate according to Example 2 of the present invention. Referring to FIG. 6, GaN and $Ga_xIn_{1-x}N$ ($0 \leq x \leq 1$) thin films are periodically and alternately grown on a chemically cleaned sapphire substrate at a first (low) temperature of 525 °C. The film thickness of GaN and $Ga_xIn_{1-x}N$ are set to 3 nm and 5 nm, respectively. The number of the periods of the $GaN/Ga_xIn_{1-x}N$ is changed from 2 to 12, corresponding to a total layer thickness of the multi-layered buffer varying from 16 nm to 96 nm. After the growth of the multi-layered buffer, a 2 μm-thick Si-doped n-type GaN epitaxial layer (monocrystalline) is grown on the surface of the formed multi-layered buffer at a second (high) temperature of 1,050 °C.

Note that the multi-layered buffer in Example 1 consisted of GaN and $Ga_xAl_{1-x}N$, whereas GaN and $Ga_xIn_{1-x}N$ are used as the buffer here. Since the melting point of InN (1,100 °C) is much lower than that of GaN (1,700 °C) and AlN (3,000 °C), it is easy for the amorphous or polycrystalline $GaN/Ga_xIn_{1-x}N$ multi-layered buffer formed at low temperature to convert into monocrystalline as the temperature is raised to a high temperature. In other words, seed crystals with low orientational fluctuation can be obtained more easily by using the GaN/GaInN combination rather than by using the GaN/AlGaN combination. In addition, an improvement in the crystalline quality of GaInN can be expected when using such a GaN/GaInN multi-layered buffer, since the GaInN-based epitaxial layers are grown on the buffer layer consisting of similar material. This characteristic indicates that the multi-layer buffer of the present invention is of much greater flexibility in choosing the constituent materials of the buffer as compared with the conventional methods, which may play a crucial role in improving the crystalline quality of the group-III nitride-based compound semiconductors.

Example 3

FIG. 7 is a schematic sectional view showing a p-type $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) crystal grown on an alternately formed but nonperiodic $GaN/Ga_yAl_{1-y}N$ ($0 \leq y \leq 1$) multi-layered buffer in which each GaN or $Ga_yAl_{1-y}N$ layer has different layer thickness on a sapphire substrate according to Example 3 of the present invention. Referring to FIG. 7, GaN and

$Ga_yAl_{1-y}N$ ($0 \leq y \leq 1$) thin films are alternately grown at a first (low) temperature of 525 °C.

but varying nonperiodically in layer thickness on a cleaned sapphire substrate. The film thicknesses of GaN/$Ga_yIn_{1-y}N$ are set to 2 and 4 nm, 3 and 5 nm, and 4 and 6 nm, respectively. The total layer thickness of the multi-layered buffer is hence 24 nm. After the growth of the multi-layered buffer, a 2 μm-thick Mg-doped p-type $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) epitaxial layer (monocrystalline) is grown on the surface of the formed multi-layered buffer at a second (high) temperature of 1,050 °C.

Note that as compared with the Examples 1 and 2, the GaN/$Ga_yAl_{1-y}N$ ($0 \leq y \leq 1$) multi-layered buffer in this example is formed nonperiodically in layer thickness. This feature demonstrates that besides the great flexibility in choosing the constituent materials, the multi-layer buffer of the present invention can even be formed nonperiodically in layer thickness. In contrast, a superlattice or a quantum wells structure must be formed strictly periodically in layer thickness as well as the solid composition. This is another flexibility provided by the introduction of the multi-layered buffer and an important advantage over the conventional single or double buffer.

Example 4

FIG. 8 is a schematic sectional view showing a n-type $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) crystal grown on a nonperiodic and alternating GaN/$Ga_yIn_{1-y}N$ ($0 \leq y \leq 1$) multi-layered buffer in which each $Ga_yIn_{1-y}N$ layer has different y value, i.e. different Ga and In composition on a sapphire substrate according to Example 4 of the present invention. Referring to FIG. 8, GaN and $Ga_yIn_{1-y}N$ ($0 \leq y \leq 1$) thin films are alternately grown at a first (low) temperature of 525 °C but nonperiodic in solid composition on a chemically cleaned sapphire substrate. The film thickness of GaN and $Ga_yIn_{1-y}N$ are set to 3 nm and 5 nm, respectively, and the number of the periods of the GaN/$Ga_yIn_{1-y}N$ is fixed at 3, corresponding to a total layer thickness of 24 nm. On the other hand, the In composition (1-y) for the $Ga_yIn_{1-y}N$ layers in sequence along the direction pointing from the sapphire substrate to the surface is, 0.10, 0.15, and 0.20, respectively. After the growth of the multi-layered buffer, a 2 μm-thick Si-doped n-type $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) epitaxial layer (monocrystalline) is grown on the surface of the formed multi-layered buffer at a second (high) temperature of 1,050 °C.

As compared with the Examples 1-3, the GaN/$Ga_yIn_{1-y}N$ ($0 \leq y \leq 1$) multi-layered buffer in this example is formed periodically in layer thickness but nonperiodically varied in Ga and In composition through the buffer. This feature indicates that besides the flexibility in choosing the constituent materials and in the thickness for each layer, the multi-layer buffer of the present invention can also be formed nonperiodically in solid composition. This flexibility is only available for the multi-layered buffer but can never be realized by using the conventional single or double buffer.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, and representative devices, shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

CLAIMS

1. A crystal growth method for the group-III nitride and related compound semiconductors, comprising:

forming a MOCVD-grown periodic or nonperiodic multi-layered buffer on a substrate at a first temperature in which the layers alternate between at least two types of compound semiconductors A and B different from each other in lattice constant, energy band gap, layer thickness, and composition; and

forming a MOCVD-grown layer at a second temperature which is higher than the first of a group-III nitride or related compound semiconductor on the formed multi-layered buffer.

2. A crystal growth method according to claim 1, further comprising doping a n- or p-type in said group-III nitride or related compound semiconductor.

3. A crystal growth method according to claim 1, wherein the compound semiconductors A and B are alternately and periodically grown by MOCVD on said substrate in the sequence of AB......AB to form said multi-layered buffer.

4. A crystal growth method according to claim 1, wherein the compound semiconductors A and B are alternately grown by MOCVD on a substrate in the sequence of AB......AB varying in thickness of each layer to form a multi-layered buffer.

5. A crystal growth method according to claim 1, wherein a number of compound semiconductors A, B, C .... form a sequence of ABC..... wherein said sequence is alternately grown on said substrate at said first temperature to form said multi-layered buffer, and wherein said compound semiconductors are different from each other in lattice constant, energy band gap, layer thickness, and composition.

6. A crystal growth method according to claims 1,3, 4 or 5, wherein said substrate is made of sapphire wafer with any possible orientation.

7. A crystal growth method according to claims 1, 3, 4 or 5, wherein said first temperature is around 525 °C and said second temperature is around 1,050 °C.

8. A crystal growth method according to claim 3, wherein said

multi-layered buffer consists of three periods of repeated AB units and the total layer thickness of said multi-layered buffer is approximately 24 nm.

9. A crystal growth method according to claims 3, 4, or 8, wherein said compound semiconductors A and B are made of GaN and $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$), respectively.

10. A crystal growth method according to claims 3, 4, or 8, wherein said compound semiconductors A and B are made of GaN and $Ga_yIn_{1-y}N$ ($0 \leq y \leq 1$), respectively.

11. A crystal growth method according to claim 5, wherein said compound semiconductors A, B, C, ... are made of GaN, $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$), $Ga_yIn_{1-y}N$ ($0 \leq y \leq 1$)......, respectively.

12. A group-III nitride or related compound semiconductor, comprising:

a MOCVD-grown periodic or nonperiodic multi-layered buffer on a substrate at a first temperature in which the layers alternate between at least two types of compound semiconductors A and B different from each other in lattice constant, energy band gap, layer thickness, and composition; and

a MOCVD-grown layer at a second temperature which is higher than the first of a group-III nitride or related compound semiconductor on the formed multi-layered buffer.

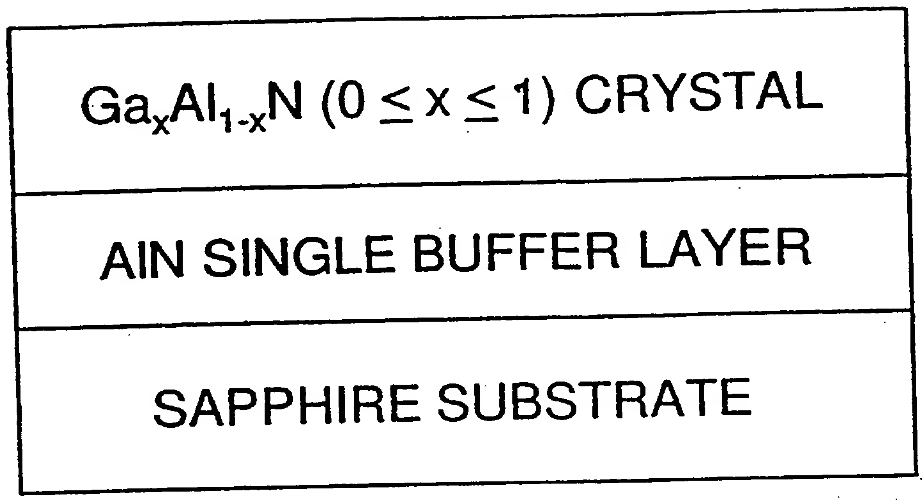

$Ga_xAl_{1-x}N$ $(0 \leq x \leq 1)$ CRYSTAL
AlN SINGLE BUFFER LAYER
SAPPHIRE SUBSTRATE

FIG. 1

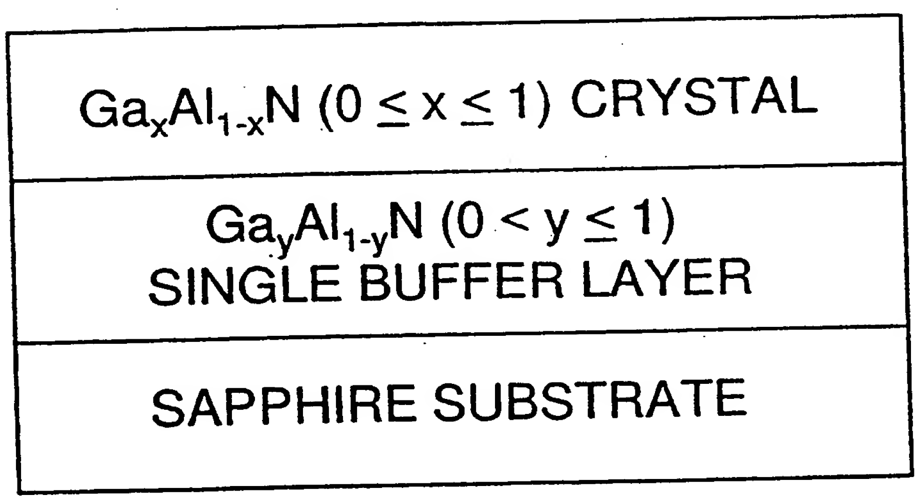

$Ga_xAl_{1-x}N$ $(0 \leq x \leq 1)$ CRYSTAL
$Ga_yAl_{1-y}N$ $(0 < y \leq 1)$
SINGLE BUFFER LAYER
SAPPHIRE SUBSTRATE

FIG. 2

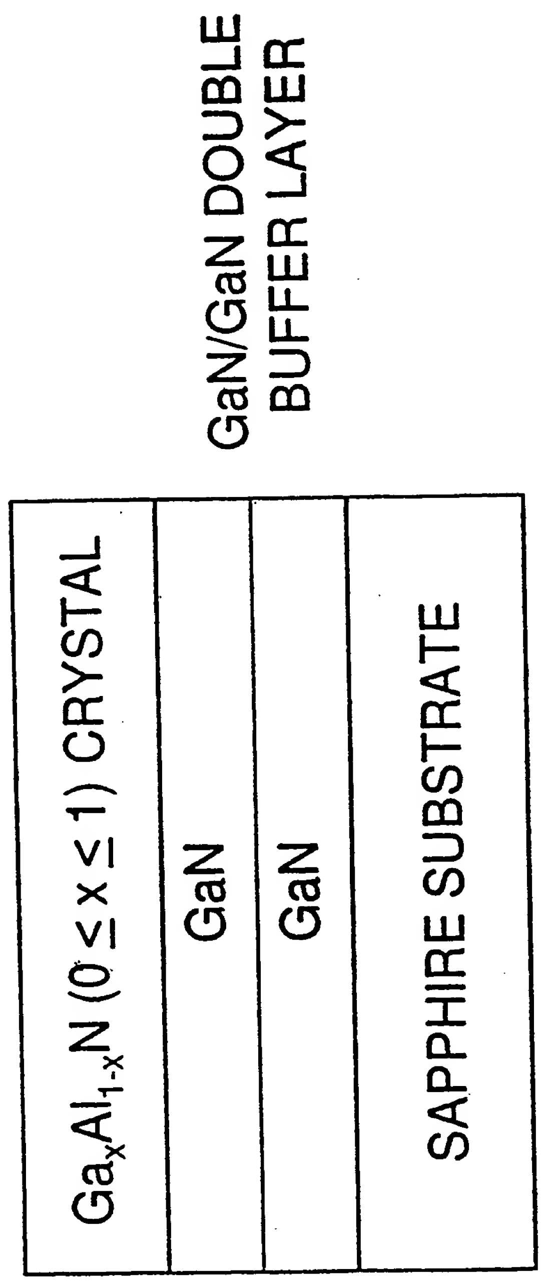

GaN/GaN DOUBLE BUFFER LAYER
$Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$) CRYSTAL
GaN
GaN
SAPPHIRE SUBSTRATE

FIG. 3

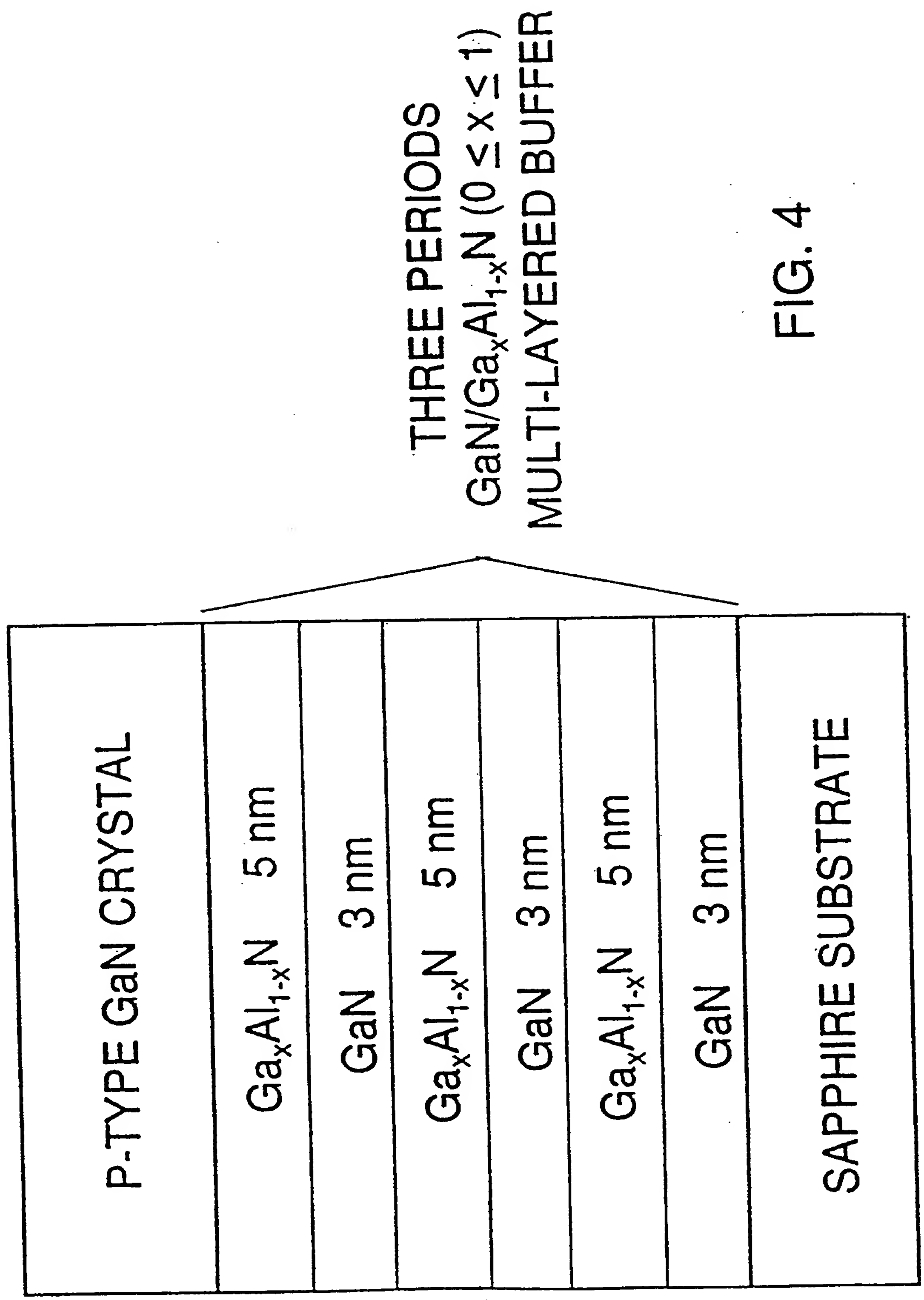
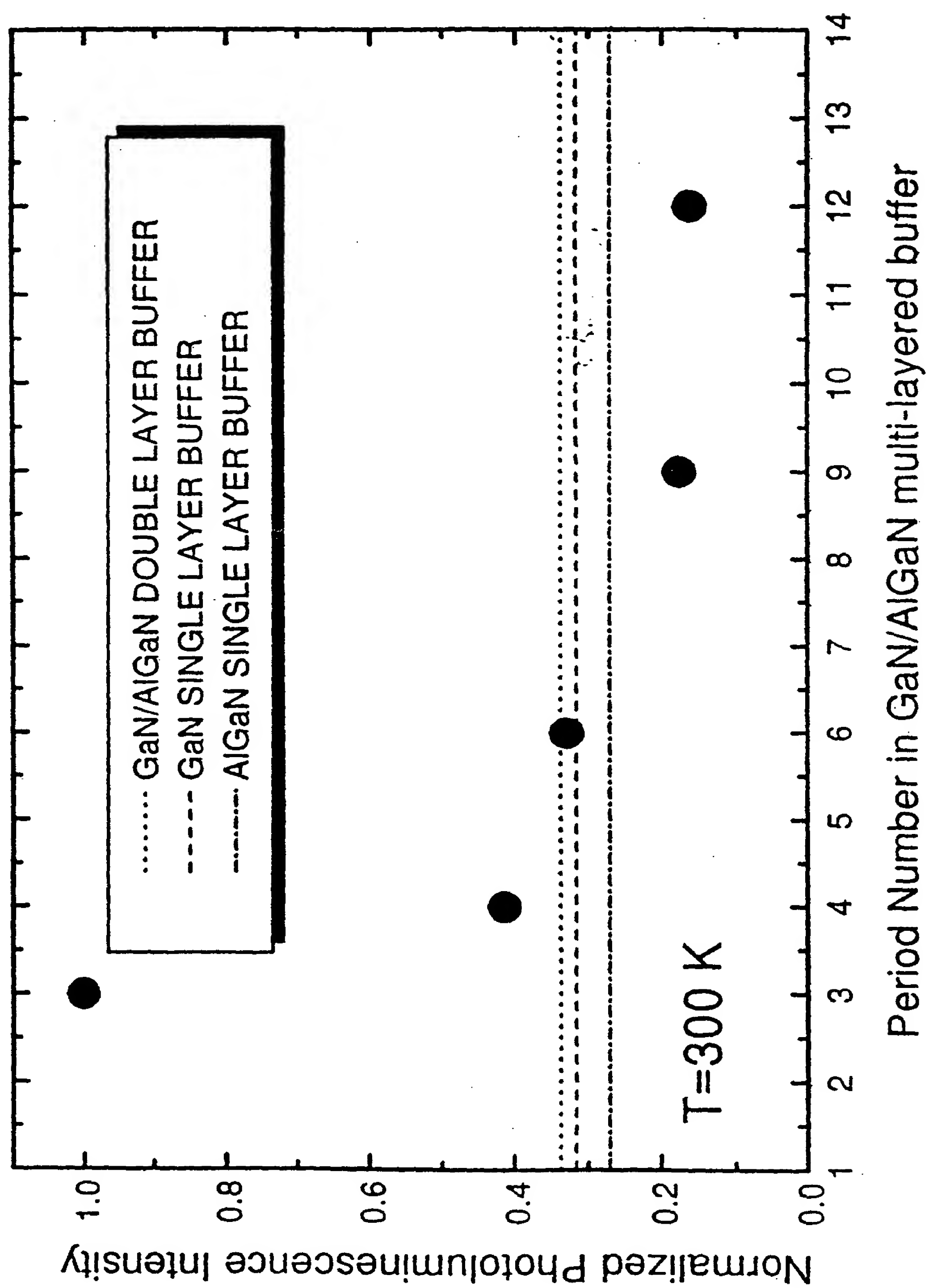

THREE PERIODS
GaN/$Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$)
MULTI-LAYERED BUFFER
P-TYPE GaN CRYSTAL
$Ga_xAl_{1-x}N$ 5 nm
GaN 3 nm
$Ga_xAl_{1-x}N$ 5 nm
GaN 3 nm
$Ga_xAl_{1-x}N$ 5 nm
GaN 3 nm
SAPPHIRE SUBSTRATE

FIG. 4

FIG. 5


GaN/AlGaN DOUBLE LAYER BUFFER
GaN SINGLE LAYER BUFFER
AlGaN SINGLE LAYER BUFFER
T=300 K
Period Number in GaN/AlGaN multi-layered buffer
Normalized Photoluminescence Intensity
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

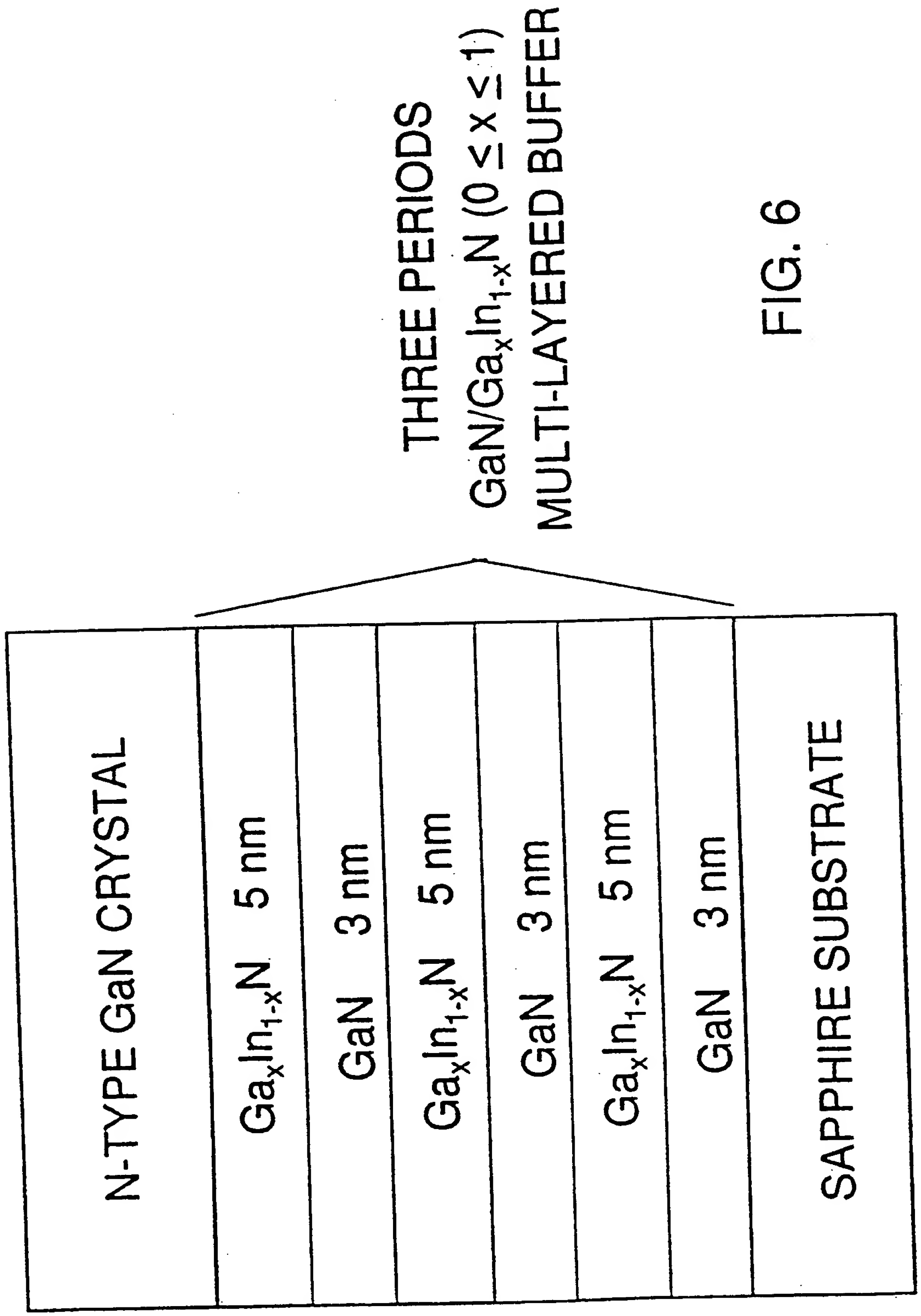

THREE PERIODS
$GaN/Ga_xIn_{1-x}N$ ($0 \leq x \leq 1$)
MULTI-LAYERED BUFFER
N-TYPE GaN CRYSTAL
$Ga_xIn_{1-x}N$ 5 nm
GaN 3 nm
$Ga_xIn_{1-x}N$ 5 nm
GaN 3 nm
$Ga_xIn_{1-x}N$ 5 nm
GaN 3 nm
SAPPHIRE SUBSTRATE

FIG. 6

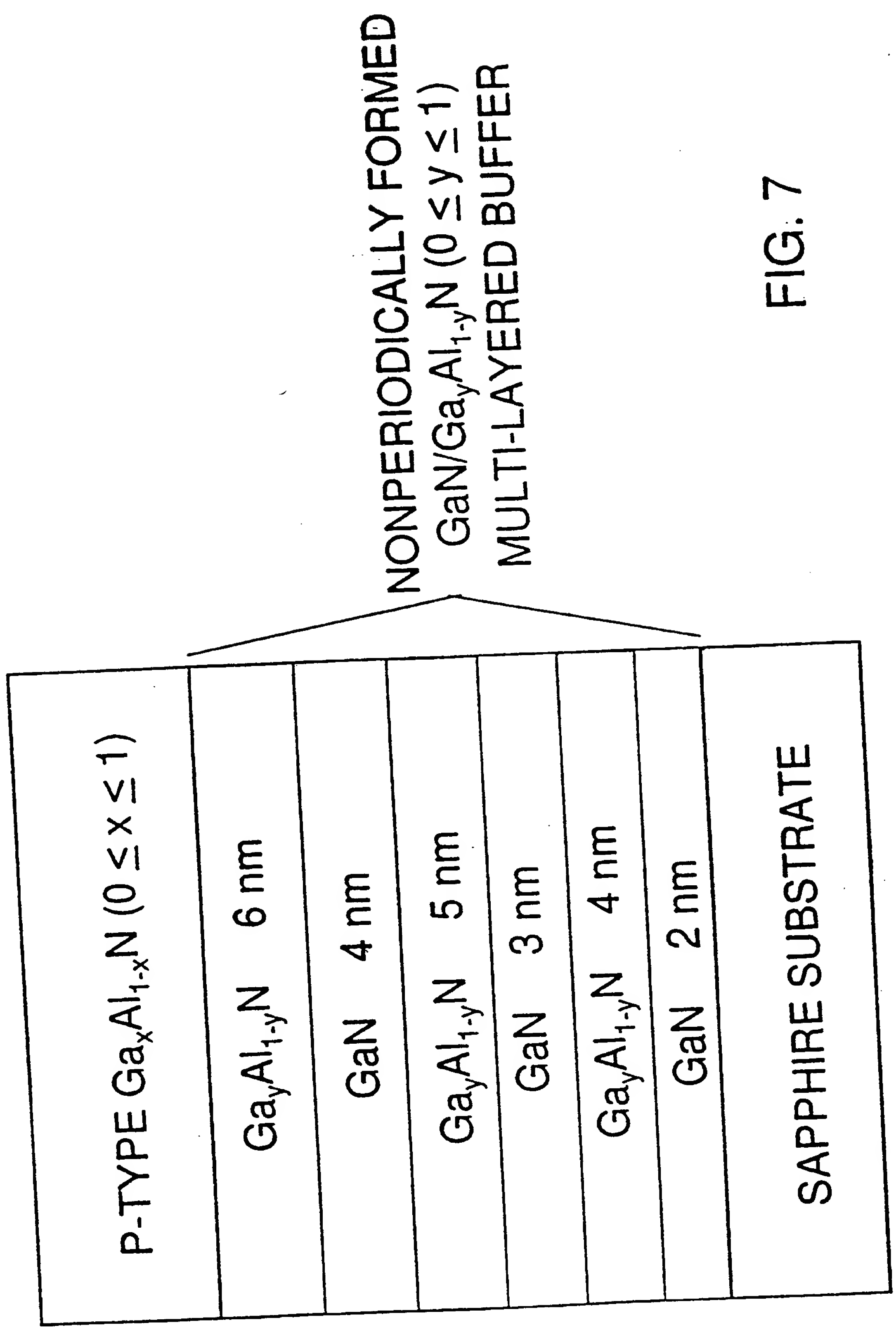

NONPERIODICALLY FORMED
GaN/$Ga_yAl_{1-y}N$ ($0 \leq y \leq 1$)
MULTI-LAYERED BUFFER
P-TYPE $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$)
$Ga_yAl_{1-y}N$ 6 nm
GaN 4 nm
$Ga_yAl_{1-y}N$ 5 nm
GaN 3 nm
$Ga_yAl_{1-y}N$ 4 nm
GaN 2 nm
SAPPHIRE SUBSTRATE

FIG. 7

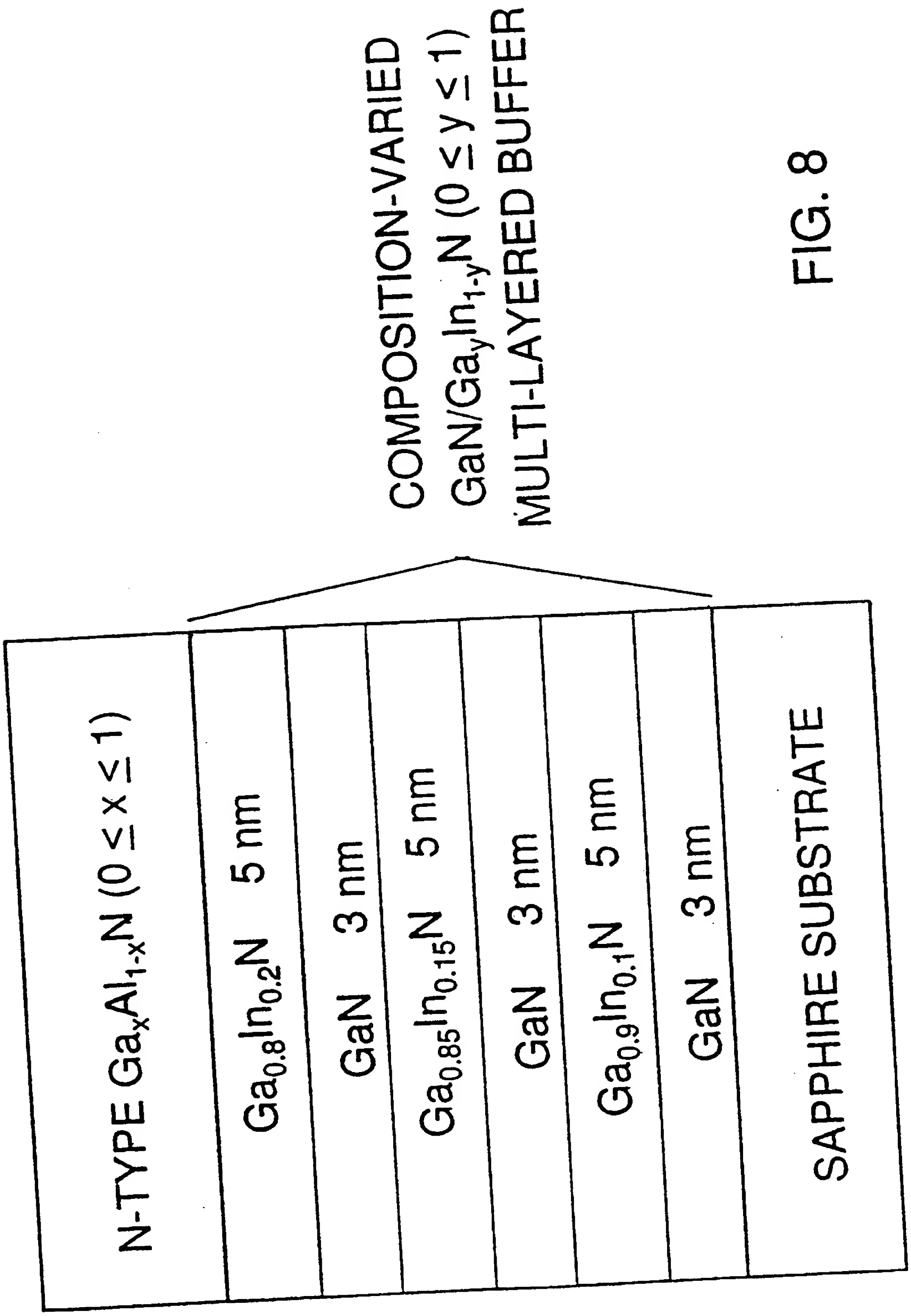

COMPOSITION-VARIED
GaN/$Ga_yIn_{1-y}N$ ($0 \leq y \leq 1$)
MULTI-LAYERED BUFFER
N-TYPE $Ga_xAl_{1-x}N$ ($0 \leq x \leq 1$)
$Ga_{0.8}In_{0.2}N$ 5 nm
GaN 3 nm
$Ga_{0.85}In_{0.15}N$ 5 nm
GaN 3 nm
$Ga_{0.9}In_{0.1}N$ 5 nm
GaN 3 nm
SAPPHIRE SUBSTRATE

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG 99/00039

A. CLASSIFICATION OF SUBJECT MATTER

IPC^6: H 01 L 21/205

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC^6: H 01 L; H 01 S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	US 5 863 811 A (KAWAI et al.), 26 January 1999 (26.01.99), totality.	
A	Patent Abstracts of Japan, Vol.96, No.1, 31 January 1996 (31.01.96) & JP 07-235 692 A (SONY), 05 September 1995 (05.09.95).	1-12
A	Patent Abstracts of Japan, unex.applic. E Section, Vol.17, Nr.466 (25.August 1993), The Patent Office Japanese Government, page 34E1421, Kokai No. A5-110138 (NICHIA CHEM.).	1-12

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
„A" document defining the general state of the art which is not considered to be of particular relevance
„E" earlier application or patent but published on or after the international filing date
„L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
„O" document referring to an oral disclosure, use, exhibition or other means
„P" document published prior to the international filing date but later than the priority date claimed
„T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
„X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
„Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
„&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 September 1999 (08.09.99)	16 September 1999 (16.09.99)

Name and mailing adress of the ISA/AT	Authorized officer
Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna Facsimile No. 1/53424/200	Mayer Telephone No. 1/53424/452

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SG 99/00039

Im Recherchenbericht angeführtes Patentdokument Patent document cited in search report Document de brevet cité dans le rapport de recherche	Datum der Veröffentlichung Publication date Date de publication	Mitglied(er) der Patentfamilie Patent family member(s) Membre(s) de la famille de brevets	Datum der Veröffentlichung Publication date Date de publication
US A 5863811	26-01-1999	JP A2 9018092	17-01-1997
JP A2 7235692	05-09-1995	keine - none - rien	